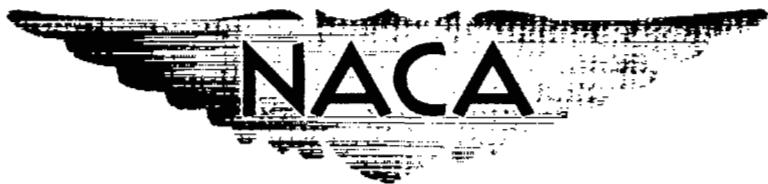


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# RESEARCH MEMORANDUM

SOME DIELECTRIC PROPERTIES OF SUSPENSIONS OF

BORON POWDERS IN MINERAL OIL

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FOR AERONAUTICS**

WASHINGTON

August 18, 1955

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

## SOME DIELECTRIC PROPERTIES OF SUSPENSIONS OF

## BORON POWDERS IN MINERAL OIL

By Aubrey P. Altshuller

## SUMMARY

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The dielectric constant for suspensions of two types of boron powder in mineral oil was measured as a function of concentration of boron particles, moisture content, temperature, and frequency of oscillation. Also investigated were the effects of boron-powder concentration and moisture content on the dielectric losses (dissipation factors) of mineral-oil suspensions of the two boron powders.

The dielectric constants of the suspensions depend strongly on the concentration of boron powder. Differences in concentration and moisture content are readily detectable from the dielectric-constant measurements. The suspensions of the two types of boron powder in mineral oil show differences in dielectric constant at the higher concentrations of the powder. These differences may result from small variations in shape, from irregularities on the surfaces of the particles, and from agglomeration and flocculation. Differences may also result from the nature of the impurities present.

## INTRODUCTION

As part of the program involving the evaluation of slurries of magnesium and boron powders in hydrocarbons as fuels for ram-jet and afterburner applications (refs. 1 to 3), various physical properties of such slurry fuels were investigated (refs. 4 to 8). The dielectric properties of magnesium powders in mineral oil were studied previously (ref. 8). As an extension of the physical properties program, an investigation was conducted and is reported herein on the dielectric properties for suspensions of boron powders in mineral oil. While a number of experimental investigations of the dielectric properties of various solids in nonpolar liquids have been made (refs. 8 to 12), no previous studies of the dielectric properties of boron powders in liquids have been reported.

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Since the dielectric constants of suspensions depend on the concentration of solids, the solid concentrations may in turn be obtained from dielectric-constant measurements by calibration. If the concentration of solids and the dielectric constants of the components are known, information may be obtained about the shapes of the suspended particles (refs. 8, 13, and 14). The presence of polar impurities such as water may be detected and the concentration of adsorbed impurities may be determined from the effects of such impurities on the dielectric constants of the suspensions.

The variation of the dielectric constants and dielectric losses were measured as a function of concentration for two types of boron powder in mineral oil. The temperature coefficient of the dielectric constant was determined for several concentrations of boron powders in mineral oil. The effects of moisture content of boron powders were obtained by measuring the dielectric constants and dielectric losses of suspensions prepared with both dried and undried boron powders. The effects were measured of the variation of the frequency of oscillation on the dielectric constant of suspensions of boron particles in mineral oil.

#### THEORY

The dielectric constants of suspensions of particles in liquids depend strongly on the volume fraction of solids, the ratio of the dielectric constant of the solid to that of the liquid dispersing medium, and the shape of the particles (refs. 8 to 12). It is generally assumed that the dielectric constant is independent of the size of the particles (refs. 9 and 10). A previous study (ref. 8) provided experimental evidence that the dielectric constants of mineral-oil suspensions of spherical magnesium particles are independent of particle size in the particle-size range from 2 to 20 microns. Surface impurities resulting from oxidation (ref. 8) and adsorption of moisture (present study) also may have important effects on the dielectric constants of suspensions.

The dielectric constant of a suspension of  $J$  kinds of ellipsoidal homogeneous particles suspended at random in a liquid medium is given by the expression (refs. 13 and 14)

$$\epsilon = \epsilon_D \left[ 1 - \frac{1}{3} \sum_J v_J (\epsilon_J - \epsilon_D) \sum_{i=1}^3 \frac{1}{\epsilon + (\epsilon_J - \epsilon) A_i} \right]^{-1} \quad (1)$$

where  $\epsilon_D$  and  $\epsilon_J$  are the dielectric constants of the medium and the  $J$  kinds of particles in the medium,  $v_J$  is the volume fraction of the  $J^{th}$  kind of particle, and  $A_i$  is an elliptic integral (refs. 13 and

14) that depends on the ratio of the axes of the ellipsoidal particles. For only two substances, a solid and a liquid medium,  $\epsilon_J = \epsilon_p$  and equation (1) becomes

$$\epsilon = \epsilon_D \left[ 1 - \frac{1}{3}V(\epsilon_p - \epsilon_D) \sum_{i=1}^3 \frac{1}{\epsilon + (\epsilon_p - \epsilon_D)A_i} \right]^{-1} \quad (2)$$

At low concentrations of particles, all terms in the series expansion of equation (2) beyond the linear term become negligible and equation (2) may be written as follows ( $\epsilon \rightarrow \epsilon_D$  as  $V \rightarrow 0$ ):

$$\epsilon = \epsilon_D \left[ 1 + \frac{1}{3}V(\epsilon_p - \epsilon_D) \sum_{i=1}^3 \frac{1}{\epsilon_D + (\epsilon_p - \epsilon_D)A_i} \right] \quad (3)$$

If the particles are spherical in shape, equation (3) reduces to the following form:

$$\epsilon = \epsilon_D \left( 1 + 3V \frac{\epsilon_p - \epsilon_D}{\epsilon_p + 2\epsilon_D} \right) = \epsilon_D (1 + \beta_s V) \quad (4)$$

where

$$\beta_s = 3 \frac{\epsilon_p - \epsilon_D}{\epsilon_p + 2\epsilon_D}$$

For spherical particles in suspension, the dielectric constant at a given frequency is related to the dielectric constant at infinite frequency by the expression (ref. 15)

$$\epsilon = \epsilon_\infty \left( 1 + \frac{K}{1 + \omega_T^2 \tau^2} \right) \quad (5)$$

where

$\epsilon$  dielectric constant at a given frequency

$\epsilon_\infty$  dielectric constant at infinite frequency

$\omega$   $2\pi$  times frequency

$$K = \frac{9V\epsilon_D}{2\epsilon_D + \epsilon_p}$$

$$T = \frac{2\epsilon_D + \epsilon_p}{4\pi\sigma_p}$$

$\sigma_p$  conductivity of dispersed particles

For semiconducting and nonconducting spherical particles with dielectric constants  $\epsilon_p$  between 2 and 50 in a nonpolar liquid with a dielectric constant  $\epsilon_D$  around 2,  $K$  ranges from  $3V$  to  $\frac{1}{3}V$  and  $T$  ranges from  $\frac{1}{2}\sigma_p^{-1}$  to  $4\sigma_p^{-1}$ . If  $K$  is approximated as  $V$  and  $T$  as  $\sigma_p^{-1}$ , equation (5) reduced to the approximate form

$$\epsilon \approx \epsilon_\infty \left( 1 + \frac{V}{1 + \omega^2/\sigma_p^2} \right) \quad (6)$$

When  $\omega^2/\sigma_p^2 \gg 1$ , the second term in parenthesis is very nearly zero and  $\epsilon$  is independent of the frequency.

For boron powders in mineral oil, where  $\epsilon_D = 2.2$ ,  $\epsilon_p = 12$  (ref. 16),  $K = 1.2V$ , and  $T = 1.3/\sigma_p$ , equation (6) is a very good approximation.

An experimental study of the conductivity of boron (ref. 17) prepared by the thermal decomposition of diborane showed a very strong dependence of the conductivity on the decomposition temperature. The values of  $\sigma_p$  at room temperature for largely crystalline boron varied widely in the range from 10 to  $10^{-12}$  mho per centimeter. For samples of mostly amorphous boron (ref. 17),  $\sigma_p$  ranged from 1 to  $10^{-8}$  mho per centimeter. For these ranges of conductivities,  $\omega^2/\sigma_p^2$  is much greater than 1 (except for frequencies below 100 cycles per second and for  $\sigma_p$  values greater than 10). Consequently as  $\epsilon$  approaches  $\epsilon_\infty (\omega^2/\sigma_p^2 \gg 1)$  the dielectric constants of spherical boron particles suspended in mineral oil should be largely independent of the frequency. The equation relating the dielectric constant to frequency for nonspherical particles (ref. 16) is considerably more complicated. However, for ratios of  $\omega^2$  to  $\sigma_p^2$  much greater than 1, the effect of  $\omega^2/\sigma_p^2$  should be more important than the effect of shape. Therefore, even for nonspherical boron particles suspended in mineral oil, the dielectric constant should be fairly independent of frequency.

## EXPERIMENTAL PROCEDURE

## Materials

A single batch of purified white mineral oil was used throughout this study. The dielectric constant of the mineral oil was found to be 2.169 at 20° C and 2.143 at 40° C. The density of this mineral oil was 0.8696 gram per milliliter at 20° C. The viscosity of the mineral oil as determined with a Brookfield viscometer was 40 centipoises at 30° C.

Two types of boron powder were used. One was prepared by reduction of the boric oxide with magnesium to give a boron powder of 89 percent elemental boron content. This boron powder will be referred to as MgRd powder. The other boron powder had been prepared by electrolytic reduction which gave a boron powder of 95 percent elemental boron content. This second boron powder will be referred to as ElRd powder. The average equivalent spherical particle diameter for each of the powders was found to be around 1 micron as determined by the air permeability method using the Fisher Sub-Sieve Sizer. When dried boron powders were desired, the powders were dried in a vacuum oven at 60° C overnight and then placed in a desiccator over anhydrous calcium sulfate for several days. The ElRd powder lost about 0.5 and the MgRd powder about 0.25 percent in weight by this procedure.

In order to estimate the concentration of acidic impurities, 1 gram of these boron powders was stirred with 100 milliliters of water, the boron was filtered off, and the pH of the extract was measured (ref. 7). The distilled water used had a pH of 5.9. The extracts of undried and dried MgRd boron powders both had pH's of about 6. The extract of dried ElRd boron powder had a pH of 5. None of these pH values indicate appreciable amounts of acidic impurities.

## Preparation of Suspensions

The suspensions were prepared by weighing first boron powder and then the mineral oil into a beaker placed on a balance sensitive to 0.1 gram. The total weight of materials used was 200 grams. The suspensions were stirred vigorously for 15 minutes to 1/2 hour with a motor-driven stirrer. The beaker containing the suspension was then placed in a constant temperature bath. The temperature of the suspension was adjusted to within 1° of the temperature to be used in the measurement. The suspension was poured rapidly into the dielectric-constant cell and measurements were begun at once. The suspensions prepared from the ElRd boron powder were quite smooth in appearance which probably indicated good dispersion of the particles. However, the suspension prepared with MgRd boron particles despite prolonged stirring contained some small agglomerates of boron. The mineral-oil suspensions were so viscous above 20 percent by weight boron that the dielectric-constant cell could not be filled properly with the suspension.

### Dielectric-Constant Apparatus

A Schering capacitance bridge was used to make the dielectric-constant and dielectric-loss measurements. The substitution method was used whereby the capacity introduced by the suspension in the dielectric-constant cell was removed by reducing the capacity of the precision condenser which was in parallel with the cell.

The dielectric-constant cell consisted of two concentric brass cylinders fitted into a Bakelite top. Both cylinders and the Bakelite top were threaded. The cylinders were closed at the bottom, and the outer cylinder also served as a container for the material being measured. Two holes were tapped so that screws could make connection with the top edges of the cylinders and thus could serve as terminals.

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Further details on the capacitance bridge, dielectric-constant cell and the calibration of the cell have been given previously in reference 8.

The temperature of the suspension was maintained at 20° or 40° C by circulating water, maintained constant to 0.2° C, from a temperature bath into a stainless-steel jacket surrounding the dielectric-constant cell.

### Instrumental Accuracy, Reproducibility, and Sensitivity

The reproducibility and accuracy of the dielectric-constant apparatus were tested by the use of purified hydrocarbons (ref. 8). The reproducibility with hydrocarbons was better than  $\pm 0.1$  percent, and the accuracy using hydrocarbons was  $\pm 0.1$  to  $\pm 0.2$  percent. The cell was recalibrated with air and benzene before each determination.

When suspensions are used, the over-all reproducibility and accuracy diminish somewhat because of the multiphase systems involved. Heterogeneities due to imperfect mixing and the rapid settling of particles decrease the reproducibility in varying amounts depending on the type of boron powder and the concentration of the powder in the suspension. The over-all reproducibility of the dielectric constants for such multiphase systems is in the range between 0.25 and 1 percent. The dielectric-loss readings could be reproduced to within 5 to 10 percent.

### EXPERIMENTAL RESULTS AND DISCUSSION

The values obtained from dielectric-constant and dielectric-loss measurements on suspensions of boron powders in mineral oil are listed in tables I to III. These measurements were taken at a frequency of

1000 cycles per second, except when the effect of frequency was investigated. Results are listed for the two different boron powders available, the one produced by the magnesium reduction process, MgRd, and the other produced by the electrolytic reduction process, ElRd. Some data are given on the effects of temperature (table II) and moisture (tables I and III) on the dielectric-constant results. All the measurements discussed in this report were made immediately after the suspensions were poured into the dielectric-constant cell.

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### Dielectric Constants of Boron Suspensions

Effect of concentration. - The dielectric constants of the mineral-oil suspensions of dried boron powders are plotted against percent by weight of solids in figure 1. The dielectric constants of suspensions containing undried and dried boron produced by reduction with magnesium, MgRd, and dried boron produced by electrolytic reduction, ElRd, are listed in table I as functions of the percents by weight and volume of solid.

The variation of dielectric constant with volume fraction, or percent, (percent by volume = 100 volume fraction) is of more theoretical significance than with weight fraction, or percent, (percent by weight = 100 weight fraction) of solids. To calculate the volume fraction, the following formula was used:

$$V = \frac{100 d_L w_S}{w_S d_L + w_L d_S} \quad (7)$$

where

$d_S, d_L$  densities of solid and liquid, respectively

$w_S, w_L$  weight fractions of solid and liquid, respectively

The two sources of error in calculating volume percentages (100V) from weight percentages (100W) lie in the uncertainties in the density of boron and the weighing error at very low concentrations of boron in the suspension. The density of 99+ percent boron may be taken as  $2.31 \pm 0.02$  grams per milliliter (refs. 18 and 19). The densities found for various samples of boron powders (90 percent purity) used at this laboratory range from 2.29 to 2.33 grams per milliliter which give an average value for the density of  $2.31 \pm 0.02$  grams per milliliter. The similarity of the values for the two powders is partly due to the density of  $B_2O_3$  being 2.44 grams per milliliter (ref. 20) so that even considerable amounts of  $B_2O_3$  impurity would have little effect on the density. Furthermore, magnesium impurities of lower density in some of the samples of boron powder used probably cancel the small increase due to the  $B_2O_3$ .

impurity. The effect of the uncertainty in the density is most important at low concentration of boron, as is also the weighing error. These errors combine to make the volume percentages below about 2 percent by volume in error by several hundredths of a percent by volume.

The dielectric constants of the suspensions of 1-micron-boron powders used in the present study (table I and fig. 1) are of the same magnitudes as those found previously for irregularly shaped magnesium powders with average particle sizes between 1 and 2 microns (ref. 8). The dielectric constant is quite sensitive to changes in concentration of boron powders suspended in mineral oil as was found previously for magnesium powders in a mineral-oil medium. Consequently, the concentrations of a boron suspension of unknown boron content could be measured to about 0.25 percent by weight by the dielectric-constant method if a calibration curve were prepared for the material being used.

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A least-squares treatment of the data on suspensions prepared using ElRd dried boron was made. The data for dried MgRd and ElRd boron-powder concentrations up to 0.0155 volume fraction (4 percent by weight) can be represented to better than  $\pm 0.01$  dielectric-constant units by the empirical equation  $\epsilon = 2.17 + 24.0V$ . The dielectric-constant data up to 0.0155 volume fraction for suspensions prepared using undried boron powder MgRd are also represented by the empirical equation given previously. All the dielectric-constant data on mineral-oil suspensions of ElRd dried boron powder can be represented by the empirical equation

$$\epsilon = 2.16 + 23.8V + 153V^2 \text{ to about 0.01 dielectric-constant units.}$$

No agglomerates were visible to the eye in the suspensions containing very low concentrations of ElRd boron. (Agglomeration in this report refers to the clusters of individual particles that are not broken up in the mixing procedure and which therefore exist in the suspension.) Flocculation possibly could exist in the boron suspensions at very low concentrations of ElRd boron powder. (Flocculation in this report refers to the coming together of individual particles into clusters in the suspension after preparation.) However, some variation from linearity in  $\epsilon$  as a function of  $V$  should occur (ref. 10) if flocculates are building up, but no deviation from the simple linear equation  $\epsilon = 2.17(1 + 11.1V)$  is noticeable below 0.015 volume fraction (below 4 percent by weight). Therefore, it is assumed that negligible flocculation occurs below 0.015 volume fraction of boron.

A deviation from linearity on the variation of the dielectric constant of the suspensions occurs above  $1\frac{1}{2}$  percent by volume (see fig. 1). This deviation can be due to the importance of the quadratic term for concentration in the theoretical equation and can also be due to agglomeration and flocculation. Very probably in suspensions containing

more than  $1\frac{1}{2}$  percent by volume boron (4 percent by weight), agglomeration and particularly flocculation can become important, if not predominant factors, in determining the dielectric constant. Nevertheless, the dielectric constants are reproducible from 0.5 to 1 percent, indicating that the amounts of agglomeration and flocculation must reproduce themselves quite closely when averaged over a macroscopic sample.

The two types of boron-powder suspensions showed differences in dielectric constants at the higher concentrations of boron powder (above 2 percent by volume, See fig. 1). This effect may be due to small differences in shapes and irregularities between the boron particles in the two different boron powders that are not important at concentrations below about 2 percent by volume (5 percent by weight). Differences in the degree of agglomeration and flocculation could also be responsible for the differences in the dielectric constants of the boron powders in mineral oil. Since the amount of flocculation depends partly on the shapes and irregularities of the particles, the two effects are not independent of each other. The differences in the percentage of impurities in the two different boron powders may also contribute to the variation in dielectric constants at the higher concentrations of boron powders in mineral oil.

Effect of shape. - If no agglomeration or flocculation exists at very low concentrations of boron ( $V \approx 0.015$ ), the experimental slope may be used to obtain an average shape factor. The shape factor (refs. 8, 10, and 14) is a measure of the deviation of the particles from spherical shape. If the experimental data are expressible in power series form

$A(1 + BV + CV^2 + \dots)$  then  $f$ , the shape factor, is given by  $\beta/\beta_s$ , where  $\beta_s$  is the linear coefficient for spherical particles in the theoretical equation  $\epsilon = \epsilon_D(1 + \beta_s V)$ . The value of  $\beta$  from the empirical equation  $\epsilon = 2.17 + 24.0V$  is 11.1. The linear coefficient (ref. 14) for spherical particles with  $\epsilon_D = 2.2$  and  $\epsilon_p = 13$  is found

by interpolation (ref. 14) to be 1.77. Consequently,  $f$ , the shape factor, is 6.25. Such a large shape factor indicates considerable deviation from spherical shape. However, shape factors two or three times larger have been obtained from dielectric-constant measurements (ref. 10) on mineral-oil suspensions of aluminum and copper powders. The particles from these aluminum and copper powders appeared to be flat irregular leaflets when observed microscopically (ref. 10).

A more detailed measure of the shape of the particles can also be obtained (ref. 14). A theoretical coefficient  $\beta$  can be calculated (ref. 14) for prolate and oblate spheroids for a given ratio of the axes of the spheroids and for a given ratio of  $\epsilon_p$  to  $\epsilon_D$ . If this theoretical coefficient  $\beta$  is assumed equal to the experimental coefficient  $\beta$ ,

an average "equivalent" spheroidal shape can be assigned to the particles. For a linear coefficient of 11.1 and a ratio of  $\epsilon_p$  to  $\epsilon_D$  of 5.5, the particles would correspond (on the average) to plate-like particles with thicknesses much less than one-tenth the dimensions of the major axes (ref. 14). Unfortunately, the boron particles are so irregular (electron micrographs of fig. 1, ref. 7) that the theoretical equations are only semiquantitatively applicable.

Effect of moisture. - The dielectric constants of suspensions prepared with the MgRd undried and dried boron powders are plotted against percent by weight of boron in figure 2, and the values are listed in table I.

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The dielectric constants of the boron suspensions are reduced appreciably by the drying of the boron powder. For example, for 15 percent by weight boron powder in the suspension, drying reduced the dielectric constant about 0.5. The drying of this boron powder resulted in a weight loss of about 0.25 percent. Thus the dielectric constants of boron suspensions are quite sensitive to adsorbed impurities. Since the water extracts of the boron powders have pH values between 5 and 6, there probably were very little basic or acidic impurities adsorbed on the powders. The adsorbed material was most probably moisture. Since water has a dielectric constant of about 80 compared with the dielectric constant of 12 for boron, the high sensitivity of the dielectric constants of the boron suspensions to moisture is readily understandable. A similar sensitivity to other adsorbed polar impurities might also be expected.

The dielectric constants have not been obtained over a range of moisture contents. However, the dielectric-constant method does appear to offer some possibilities in the detection and determination of the amount of moisture and perhaps other polar impurities adsorbed on boron powders.

Effect of temperature. - The dielectric-constant values at 20° and 40° C for boron suspensions containing 0, 15, and 20 percent by weight boron are given in table II. Since the volume percentage of solids decreases with increasing temperature as a result of the decrease in the density of the liquid, the dielectric constants at 20° and 40° C are compared at the same percent by volume of solids in columns 5 and 6 of table II. The temperature coefficients are fairly small,  $\Delta\epsilon/\Delta_T = 0.005/^\circ\text{C}$  at 15 percent solids by weight and  $\Delta\epsilon/\Delta_T = 0.0085/^\circ\text{C}$  at 20 percent solids by weight. Thus, fluctuations of a few degrees in temperature would have little effect on the values obtained for the dielectric constants considering the over-all accuracy of measurement.

### Effect of Frequency of Oscillation

The results of measurements of the dielectric constants of boron suspensions at frequencies of oscillation between 100 and 100,000 cycles per second are plotted on figure 3. As may be seen from figure 3(a), the presence of adsorbed moisture on the ElRd boron-powder results in an appreciable decrease in dielectric constant with increasing frequency. However, a 15 percent by weight suspension prepared with carefully dried ElRd boron powder shows very little dependence of the dielectric constant on the frequency. Similarly, suspensions containing dried boron powder at concentrations of 10.0 and 12.5 percent gave dielectric-constant changes of only a few hundredths of a dielectric-constant unit over the entire frequency range (fig. 3(b)). This experimental result is in agreement with the conclusion reached in the theoretical section that the dielectric constants of the boron suspensions should be largely independent of frequency. Therefore, the appreciable variation in the dielectric constant of a boron suspension with frequency when moisture is present actually is probably the result of the varying dielectric constant of the highly polar adsorbed water molecules with frequency. Although the presence of moisture may be detected by this method, the detection and determination of moisture content probably could be accomplished more readily by measuring the changes in dielectric constant at a fixed frequency such as 1000 cycles per second.

### Dielectric Losses of Boron Suspensions

The dielectric losses (dissipation factors) of the boron suspensions in mineral oil also were measured. The values obtained for suspensions containing undried MgRd boron powder and dried MgRd and ElRd boron powders up to 15 percent by weight boron are given in table III. The values of the dielectric losses increase fairly rapidly and nonlinearly with boron-powder concentration.

Drying of MgRd boron powder did not appear to decrease the loss values very much compared with the same MgRd powder undried. This is in contrast with the dielectric-constant results that show appreciable decreases in the dielectric constant upon drying the boron powder. Why this difference in behavior should exist is not clear.

The dielectric losses of mineral-oil suspension of dried ElRd boron powder are much lower than those of mineral-oil suspensions of undried or dried MgRd boron powder. This difference in the dielectric losses can be the result of two factors: (1) MgRd boron powder has a greater percentage of impurities, and these impurities may make appreciable contributions to the observed dielectric losses. (2) Although the average shape of the particles in the two powders are apparently quite similar, there may be sufficient variation in the shapes to result in

appreciably different dielectric losses in the suspensions made with the two different powders.

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#### SUMMARY OF RESULTS

The dielectric constants and dielectric losses of suspensions of two types of boron powder in mineral oil have been measured with a Schering capacitance bridge. One of the boron powders MgRd was produced by a magnesium reduction process, while the other boron powder ElRd was produced by an electrolytic reduction process. The following results were obtained:

1. The dielectric-constant data for suspensions of boron powders in mineral oil at 20° C up to 0.0155 volume fraction (4 percent by weight) for dried and undried MgRd and dried ElRd boron powders can be represented by the empirical equation  $\epsilon = 2.17 + 24.0V$  where  $\epsilon$  is the dielectric constant and  $V$  is the volume fraction.
2. The dielectric-constant data for suspensions of boron powders in mineral oil at 20° C up to 0.086 volume fraction (20 percent by weight) for dried ElRd boron powder can be represented by the empirical equation  $\epsilon = 2.16 + 23.8V + 153V^2$ .
3. Agglomeration and flocculation probably exist in the suspensions with more than  $1\frac{1}{2}$  percent boron powder by volume. Some flocculation is possible for suspensions containing less than  $1\frac{1}{2}$  percent boron by volume, but it is considered to be unlikely.
4. The shape factors and linear coefficients obtained from an analysis of the dielectric-constant measurements indicate that the boron particles were nonspherical and probably plate-like. The average ratio of the diameter to the thickness of the "equivalent" plates is approximately 10.
5. The dielectric constant of a suspension of 15 percent MgRd boron powder by weight is reduced by 0.5 unit with removal of 0.25 percent volatile materials by weight. The pH measurements on aqueous extracts of the boron powders indicate no appreciable acidic or basic impurities; therefore, the adsorbed impurity is most probably moisture.
6. The temperature coefficients of the dielectric constant of dried ElRd boron-powder suspensions are  $0.0055/^\circ C$  for 15 percent by weight boron powder and  $0.0085/^\circ C$  for 20 percent by weight boron powder in the temperature range from 20° to 40° C.

7. For suspensions of very well dried ElRd boron powder, the dielectric constant is almost completely independent of frequency in the frequency range from 100 to 100,000 cycles per second.

8. The dielectric losses of the suspensions are small, less than 0.01 unit. Furthermore, the dielectric losses of suspensions containing ElRd boron powder are only 15 to 25 percent of the losses of suspensions containing MgRd boron powder.

#### CONCLUDING REMARKS

The dielectric-constant results on mineral-oil suspensions of boron powders indicate that the dielectric-constant measurements may be used to determine the percentage of the boron powder in the suspension once a calibration is made. The dielectric constant can probably be used also to determine the amount of volatile polar impurities, particularly water, adsorbed on the boron particles.

Lewis Flight Propulsion Laboratory.

National Advisory Committee for Aeronautics  
Cleveland, Ohio, June 6, 1955

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TABLE I. - DIELECTRIC CONSTANTS FOR 1-MICRON-BORON  
POWDERS IN MINERAL OIL AT 20° C

Solids content		Dielectric constant (1000 cps)		
Percent by weight	Percent by volume	Undried Boron powder, MgRd	Dried Boron powder, MgRd	Dried Boron powder, ElRd
0	0	2.17	2.17	2.17
2.00	.76	2.34	2.34	2.34, 2.35
3.00	1.15	2.44	----	2.45
4.00	1.55	----	----	2.54
5.00	1.94	2.68, 2.69	2.65	2.69, 2.69, 2.68
6.00	2.35	----	----	2.78
7.50	2.96	3.03, 3.06	2.93	2.99, 3.01, 3.00
9.00	3.59	----	3.12	----
10.0	4.02	3.46, 3.41	3.30, 3.35	3.37, 3.36
12.5	5.11	3.92, 3.88	3.58	3.78, 3.77
15.0	6.23	4.36, 4.40	3.89, 3.94	4.23, 4.25
20.0	8.61	----	4.92	5.33

TABLE II. - EFFECT OF TEMPERATURE ON DIELECTRIC CONSTANT OF  
SUSPENSIONS OF DRIED E1Rd BORON POWDER IN MINERAL OIL

Solids content			Dielectric constant (1000 cps)		
Percent by weight	Percent by volume, $V^{20^\circ}$	Percent by volume, $V^{40^\circ}$	$\epsilon^{20^\circ}$	$\epsilon^{20^\circ} (V^{20^\circ} = V^{40^\circ})^a$	$\epsilon^{40^\circ}$
0	0	0	2.169	2.169	2.143
15	6.23	6.14	4.24	4.19	4.08
20	8.60	8.48	5.33	5.27	5.10

<sup>a</sup>These values were obtained from figure 1.

TABLE III. - DIELECTRIC LOSSES (DISSIPATION FACTORS)  
FOR BORON SUSPENSIONS AT  $20^\circ C$

Solids content		Dielectric loss (1000 cps)		
Percent by weight	Percent by volume	Undried boron powders MgRd	Dried boron powders MgRd	Dried boron powders E1Rd
0	0	0	0	0
2.00	.76	.0005	.0004	.0001
5.00	1.94	.0013	.0016	.0003
7.50	2.96	.0032	.0030	.0004
10.0	4.02	.0041	.0041	.0005
12.5	5.11	.0080	.0058	.0008
15.0	6.23	.0087	.0080	.0015

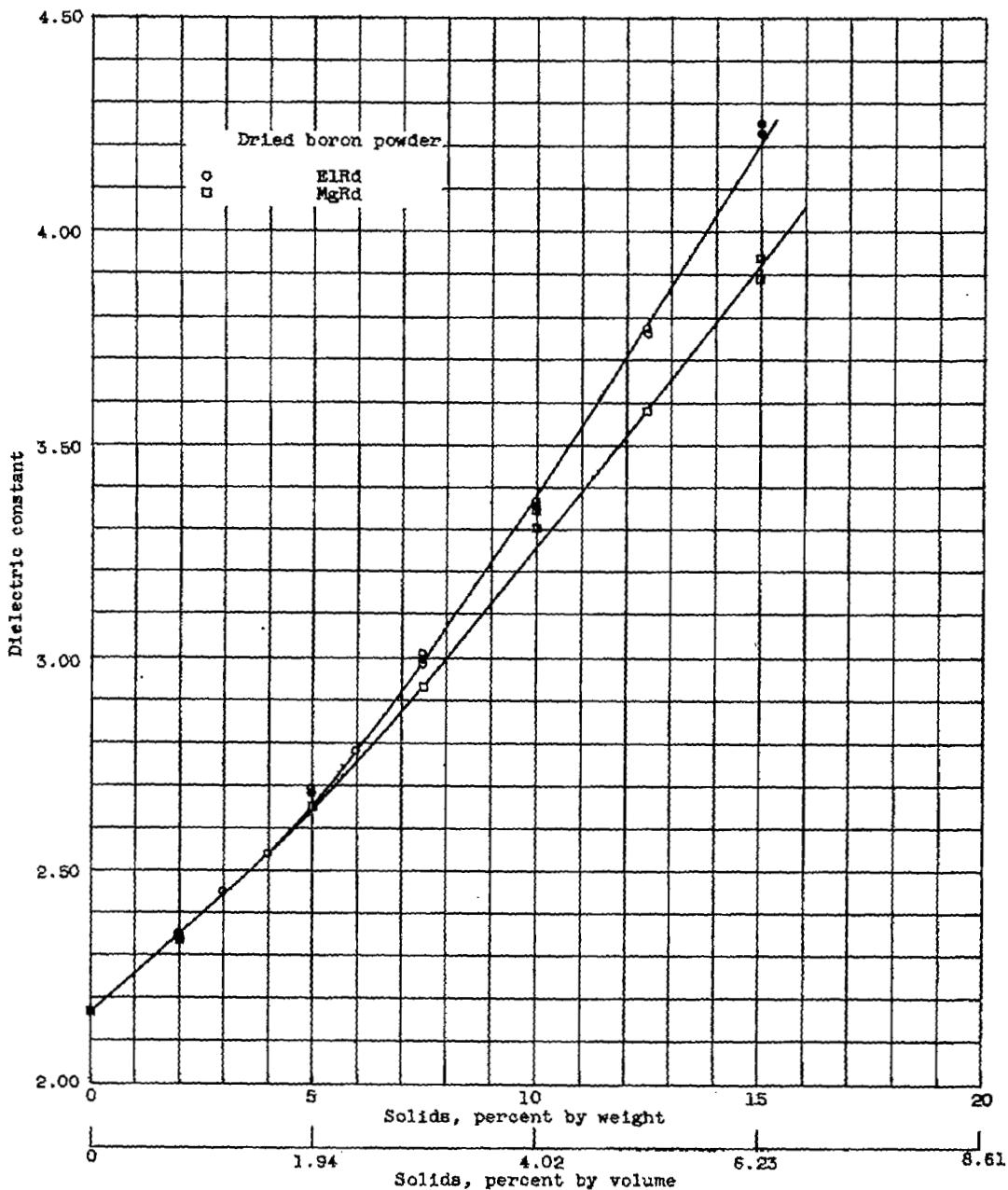


Figure 1. - Comparison of dielectric constants of suspensions of boron in mineral oil at 20° C.

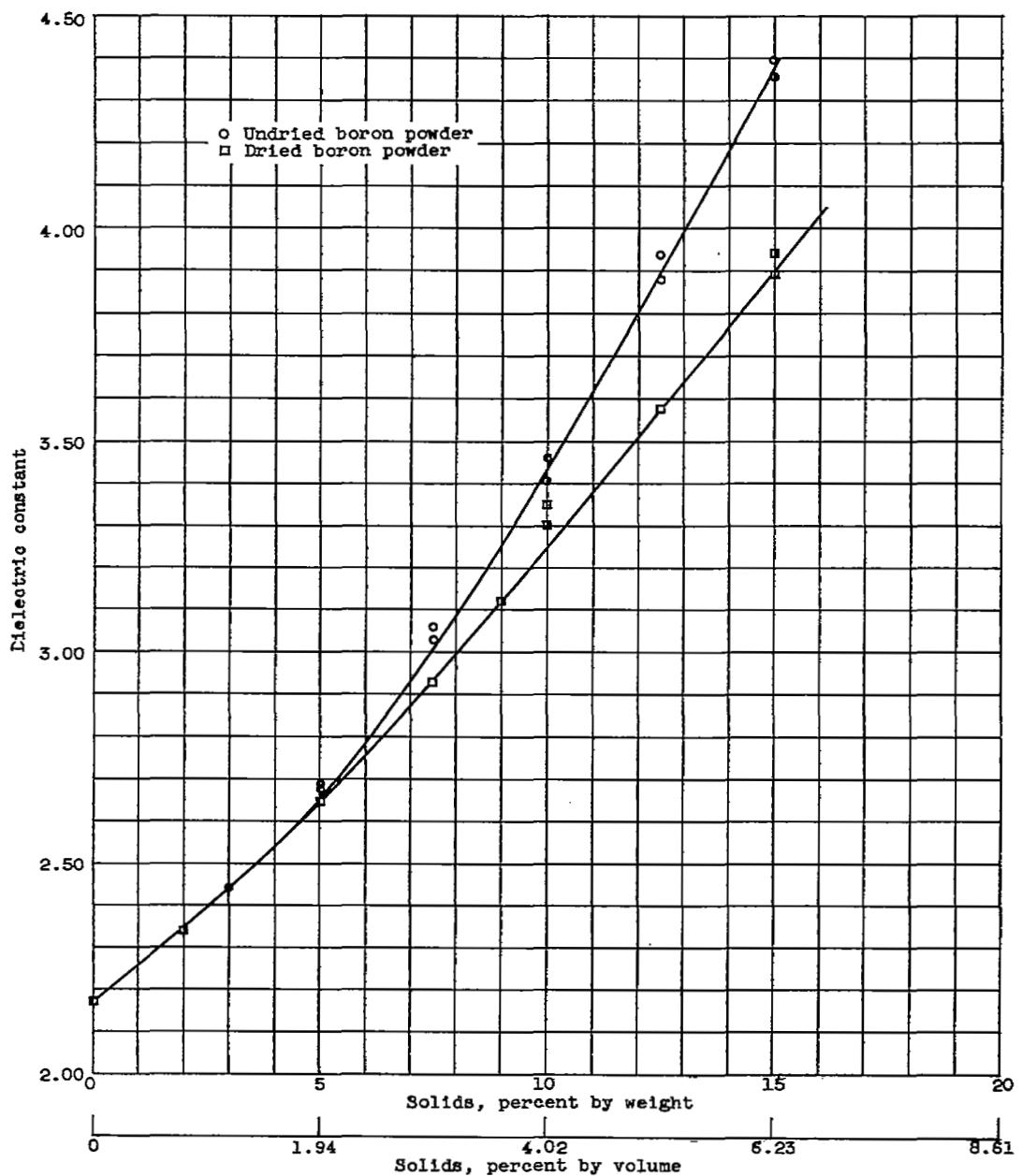


Figure 2. - Effect of drying of boron powder on dielectric constants of suspensions of boron powders in mineral oil at 20° C. Boron prepared by magnesium reduction process.

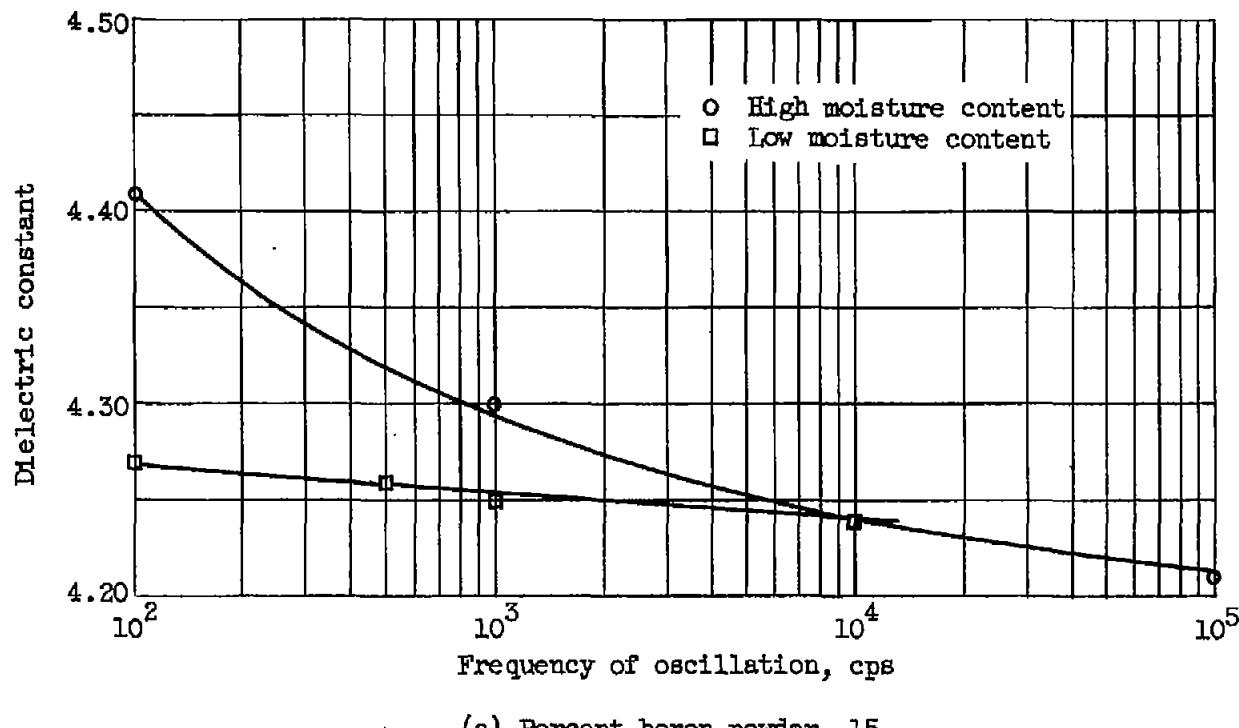
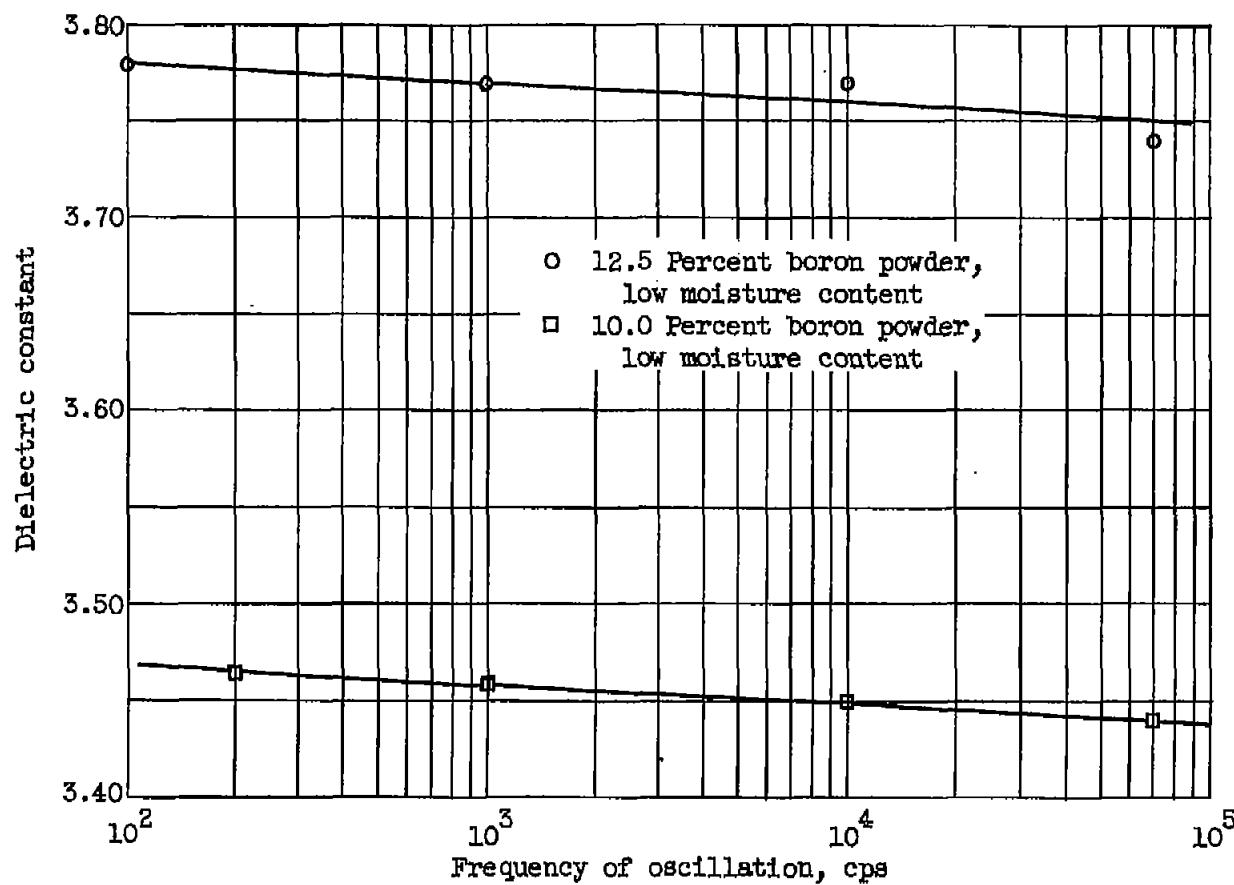


Figure 3. - Variation with frequency of dielectric constant of ElRd boron powders in mineral oil at 20° C.



(b) Percent boron powder, 12.5 and 10.0.

Figure 3. - Concluded. Variation with frequency of dielectric constant of ElRd boron powders in mineral oil at 20° C.

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